EFFICIENCY & CAPACITY OF A 200 H. P. STIRLING BOILER WITH MC KINZIE STOKER

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1910

INFLUENCE OF DEPTH OF FIRE
ON
EFFICIENCY & CAPACITY
OF A
200 H. P. STIRLING BOILER
WITH Mc KINZIE STOKER

A THESIS

PRESENTED BY

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TO THE

PRESIDENT AND FACULTY

OF

ARMOUR INSTITUTE OF TECHNOLOGY

FOR THE DEGREE OF

BACHELOR OF SCIENCE IN MECHANICAL ENGINEERING

HAVING COMPLETED THE PRESCRIBED COURSE OF STUDY IN

MECHANICAL ENGINEERING

MAY, 1910

Accepted 5/24/10
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INTRODUCTION

The aim of this thesis is to present in complete form a series of commercial boiler tests conducted as nearly as possible in every detail with the American Society of Mechanical Engineers' Code.

These tests were made on a standard two hundred and fifty horse power Stirling boiler, equipped with a McKenzie stoker. It is located at the power plant of Armour Institute of Technology, Thirty Third and Armour Avenue, Chicago, Illinois. The conditions under which these tests were run were as nearly identical to its actual operating conditions as possible, so as to make it applicable to furthering the economy of operation of this particular setting.

This boiler is of the standard Stirling type, being one of a battery of two, suspended from a steel frame. There are three upper drums and one lower, or mud drum. The setting is entirely enclosed with brick, thus reducing radiation to a minimum, and keeping the surfaces of the heated parts from sudden changes of temperature.

There are one hundred and fifty four four inch tubes, arranged in rows of fourteen. Four rows extend from the upper front drum to the mud drum, a like number from the upper middle drum and three rows from the upper rear drum. The tubes enter the drums radially so they can be expanded in, and make tight joints. By arranging them in rows of not more than four deep, enables the removal of any defective tube without having to cut out more than one good tube.

The lower or mud drum is not supported by any other means than by the tubes. This gives it freedom to move in any direction with the expansion of the tubes. This drum serves

as a distributer of the water and a settling receptacle from which the soft scale or sludge, can be removed by means of the blow off, located at the lowest point, and a large man hole in the end of the drum. The boiler is so constructed that all feed water must pass through this drum. It enters the upper rear drum first, and, being cooler than the water in the boiler, it sinks into the mud drum, where its temperature rises and causes it to pass up the tubes toward the two upper front drums. The tubes are nearly vertical so any scale which has not already been precipitated will settle back into the mud drum.

Stirling boilers do not require dry pipes because most of the ebulation takes place in the first drum. By placing the nozzle on the middle drum and connecting the other drums with it, by tubes in the steam space, there is a very marked change in velocity which enables most of the entrained water to settle out.

Another feature of advantage which is only found on this type of boiler is the arrangement of the baffles, which cause the gases to pass lengthwise of the tubes through the first two passes and across the tubes in the last pass, leaving where the feed enters. This gives a good scrubbing action with a minimum loss from friction.

-:AUXILIARIES:-

The auxiliaries necessary for the operation of this boiler are a feed pump, feed water heater and a stoker engine.

A Dean feed water pump is used, which utilizes the returns from the heating system and whatever makes up water that is necessary from the City supply. The feed water is heated to a temperature of about two hundred degrees Farenheit, by a Webster vacuum heater of the induced type, steam being supplied from the exhaust steam line, used for heating the Armour flats.

The stoker engine is of the vertical type and is a part of the equipment of the McKenzie stoker. It is direct connected to the stoker by a train of gears and a double ratchet and paul. The speed of the grate is regulated by an ordinary fly ball governor on the engine. For a large change in speed one of the two ratchets can be disengaged.

-:APPARATUS:-

The following apparatus is necessary for conducting a commercial boiler test:-

Calorimiter

Pressure Gauge

Draft Gauge

Recording Thermostat

Water Meter

Thermometers

Scales

Orsat Flue Gas Apparatus.

A throttling calorimiter made by the Carpenter Company is used to determine the quality of the steam. A regulation sampling tube as specified by the A. S. M. E. code was used to get an average sample. The sampling tube was inserted into the side of the nozzle about eight inches above the drum to obtain as near as possible, the actual quality of the steam leaving the boiler before condensation takes place.

The pressure gauge is of the Crosby type and of large size so it can be read easily by the fireman. The gauge is located five feet below the point where the tap is made into the drum. Upon calibration with the Crosby gauge testing apparatus the gauge was found to have a constant error of two and one half pounds below the actual pressure, which would be just enough to offset the column of water that would accumulate in the vertical pipe, so under operation, it would read correctly.

The draft was measured by means of a "U" tube and a one eighth inch iron pipe and rubber tube. Owing to the fact that the damper in the ash pit of the large boiler is broken, leaving a space about eighteen inches wide and nine feet long open, through which the air can rush with practically no resistance, the draft to the boiler on which these tests were made had a maximum value of an eighth of an inch. This limited the depth of fire which could be used and also the amount of

coal consumed on the grate.

A recording thermostat was used to determine the temperature of the flue gas. This was calibrated and found correct within the limits of reading for the range in temperature used.

A Worthington hot water meter was used to measure the water fed into the boiler. By making proper connections, the same feed pump was used to feed water to all the boilers. After the tests had been concluded, the meter was calibrated, using about the same flow of water per hour as was used by the boiler. A curve of calibration is herewith submitted from which the correct water in pounds per hour can be read, knowing the meter reading in gallons per hour.

This boiler has a hopper which is filled from a bin on the floor. As all the coal must be weighed before it is put into the hopper, a scales and bucket were found to be the most convenient means of handling

the fuel. Before each run a set of standard weights of about the same weight as the bucket of coal was placed on the scales to make certain that the scales were correct.

An Orsat apparatus is used to determine the percentage of Oxygen and carbon dioxcide in the flue gas. New solutions were used for each fire tests to insure that the apparatus is in proper working conditions. The apparatus is located about twenty five feet from the flue where the sample is taken. A pump of large capacity was used to suck the gas from the flue insuring an average sample of gas at all times. Analysis of the flue gas was made about once every hour, and an average of these results used.

-:DISCUSSION:-

There are many difficulties entering into the making of a boiler test which makes it difficult to keep the conditions constant. This particular test was conducted when the

boiler was in commercial operation, which caused the conditions to change owing to the fact that the load is composed of both heating and power. This boiler is also connected into the same steam line with the other boilers and as there is no non-return valve on the boiler tested, any slowing down of the feed on the other boilers would effect the pressure on the boiler under test.

A difficulty which prevented making a test with a constant speed of grate is the lack of sufficient draft to burn various thicknesses of fire at a constant speed. This makes it necessary to so adjust the speed that the grate is kept covered and yet burn all the coal before it empties into the ash pit.

For depths of fire over four inches this can be done easily until a depth of fuel has been reached where the combustion is too slow, owing to the weak draft. For depths of fuel less than four inches, the speed is so great (if the boiler is run at any capacity) that the heat from the arch is not sufficient

to ignite the coal as it is fed in allowing the fire to pass under the arch without igniting, making it necessary to stop the grate.

When these conditions have all been taken into consideration, the test resolves itself into the determination of the depth of fuel at which the efficiency of the boiler and grate and the capacity are most favorable. The efficiency of the grate and boiler and the capacity in B. H. P. have been plotted against the depth of fuel. The Boiler efficiency under the given conditions is best with a five inch fire while the capacity is a maximum with a six inchfire. This shows the most efficient condition to be with a fire about five and one half inches deep.

It will be noticed that one point on efficiency curve is very low when the depth of fuel was five and one fourth inches deep. This was due to the fact that the speed of the grate was too high and a great deal of the fuel went into the ash pit only partly burned.

SAMPLE CALCULATIONS

RUN NO. 3

Moisture in Fuel = 7104.5 x .05.11 = 363#

Fuel Consumed = 7104.5 - 363 = 67415#

Total Refuse dry = 1358.5 x .801 = 1088#

Total Combustible = 6741.5 x .9138 = 6162#

Dry Fuel per sq.ft.grate = 6741.5 ÷ (7.03 x 50) = 19.2#

Quality of Steam $= \frac{(h + .48(t - t_2) - g_1)}{h}$ 1149.6 +.48 (233-211) - 305.1/882.3 =96.9%

Factor of Evaporation = (1160.2 - 130.5)/969.7 =1.0620.

Water apparently evaporated per hr. 7060#

Evaporated into dry steam 7060 x .969 = 6851#

Evaporated from and at 212° = 7060 x 1.0620 = 7498#

Horsepower Commercial Rating = 7498 ÷ 34-1/2 = 217.3 H.P.

Calorific value per pound of fuel as fired = 12,544 x (1 - .0511) = 11,900 B.t.v.

Calorific value per pound of Combustible = 12,544 ÷ (1-.0862) =13,727 B.t.v.

Heat generated per pound dry coal = (12,544) (1-.162 +.0862) =1,0580 B.t.v.

Heat generated per pound Co mbustible as fired = (13727) (1-.162 +.0862) = 12546 B.t.v.

Heat absorbed per pound dry coal = (7498 x 969.7) ÷ 959 = 7580 B.t.v.

Heat absorbed per pound Combustible as burned (7498 x 969.7) ÷ 876.5 = 9042 B.t.v.

Efficiency of Boiler & grate = 7580/12544 = 60.4%.

Efficiency of Boiler = 9042/13727 = 65.8%

Equivalent evaporization from & at 212 per pound fuel as fired = 7498 ÷ 1010.6 = 7.42#

Cost of evaporating 1000 pounds of water from & at 212 = 210 x 1000/2000 x 7.42 = 14.14¢

SAMPLE CALCULATION

RUN NO. 1. May 2, 1910.

CALORIFIC VALUE OF COAL.

Wt. of crucible and coal - - - - - 1.5742 gm.
" " " " ash - - - - - 1.0731 "
" " " empty - - - - - - 1.0083 "
" " coal burned - - - - - - - .5659 "

Time	Reading	Time	Reading
12:07	2.39	12:14	7.20
:07-1/2	2.92	:14-1/2	7.17
:08	3.34	:15	7.15
:08-1/2	3.97	:15-1/2	7.13
:09	4.43	:16	7.13
:09-1/2	5.03	:16-1/2	7.12
:10	5.59	:17	7.12
:10-1/2	5.88	:17-1/2	7.11
:11	6.17	:18	7.10
:11-1/2	6.49	:18-1/2	7.09
:12	6.76	:19	7.08
:12-1/2	6.94	:19-1/2	7.06
:13	7.12	:20	7.04
:13-1/2	7.20	:20-1/2	7.02
:13-3/4	7.21	Radiation Correction	

SAMPLE CALCULATIONS

RUN NO.1 MAY 2, 1910.

CALORIFIC VALUE OF COAL.

Actual rise in temperature 7.21 - 2.39 = 4.82.

Radiation correction - - - 7.21 - 7.02 = .19.

Correct rise - - - - - - - - - - 5.01.

Wt. of coal used - - - - - - .5659 gm.

$$\frac{5.01 \times 3.2 \times 453.6}{5659} = 12{,}850 \text{ B.t.v.}$$

Calorimiter constant - - - - - - - 3.2

Moisture in Coal - - - - - - - 5.11%

Percentage ash - - - - - - - - 8.62

RUNNING LOG

TEST NO 1 — April 2, 10 AM

Time	Press	Fuel	Meter	Temperature Feed	Flue	Cal	O	CO_2
9:00	100	0	9950	174	610	228		
9:30	82	3040	0337	168		239	9.5	4.5
10:00	97	3195	0337	168	625	229	9.5	5.0
10:30	98	3270	0570	163		239		
11:00	92	3080	0786	168	630	237		
11:30	98	3030	0787	161		233		
12:00	94	4680	1089	160	625	231		
12:30	92	3120	1287	160		232	9.0	4.8
1:00	100	3515	1333	151	620	233		
1:33	78	3635	1553	164	620	220	9.8	5.0
1:44	93	1185	1680	154		238		
Total		31860	1786					
Av.	93.1			162.7	622	232.5	9.4	4.8

Depth of Fuel 5¼"

Speed of Grate Ft per Hr 9.32'

Draft Inches Water 1/8"

Weight of Wet Refuse 921#

Length of Run 4.44

A.A Byers

D.A Young

MECHANICAL ENGINEERING LABORATORY

ARMOUR INSTITUTE OF TECHNOLOGY

Report of Boiler Test made At Armour Institute of Technology.

For Thesis No1 *Date* May 2, 1910

Duration of Trial,	hours.	4.73
Kind of Boiler,		Sterling
Kind of Grate,		McKenzie
Grate Surface, length 9½ ft., width 5¼ ft.	sq. ft.	50
Water Heating Surface,	sq. ft.	2000
Superheating Surface,	sq. ft.	none
Area, Chimney,	sq. ft.	38.48
Height, Chimney,	ft.	175
Ratio Heating to Grate Surface,		40:1

AVERAGE PRESSURES.

Barometer,	ins. mercury.	29.5
Steam Gauge,	lbs. per sq. in.	93.1
Absolute Steam Pressure,	lbs. per sq. in.	107.6
Draught Gauge,	ins. water.	⅛"

AVERAGE TEMPERATURES.

External Air,	deg. F.	48
Boiler Room,	deg. F.	61
Flue,	deg. F.	622
Furnace,	deg. F.	——
Feed Water,	deg. F.	162.7
Steam,	deg. F.	232.5

FUEL.

Total Coal Consumed,	lbs.	3186
Moisture in Coal,	lbs.	162.8
Dry Coal Consumed,	lbs.	3023.2
Total Refuse, Dry,	lbs.	452.4
Total Refuse, Dry, Dry Coal Basis	per cent.	14.69
Total Combustible,	lbs.	2763.2
Combustible, Dry Coal Basis	per cent.	91.4

FUEL PER HOUR.

Coal as Fired per hour,	lbs.	673.8
Dry Coal, per hour,	lbs.	639.37
Combustible, per hour,	lbs.	584.1
Dry Coal, per sq. foot of Grate,	lbs.	12.78

TOTAL WATER.

Quality of Steam,	per cent.	96.8
Total Weight Water Used,	lbs.	22,798
Total Evaporated into Dry Steam,	lbs.	22,079
Factor of Evaporation,		1.06
Total from and at 212°,	lbs.	23,404

WATER PER HOUR.

Amount Used, Apparently Evaporated,	lbs.	4820
Evaporated into Dry Steam,	lbs.	4666
Evaporated from and at 212°,	lbs.	4946

EVAPORATION.

PER POUND OF FUEL AS FIRED

Apparent,	lbs.	7.15
Actual,	lbs.	6.93
Equivalent from and at 212°,	lbs.	7.34

PER POUND DRY COAL.

Apparent,	lbs.	7.54
Actual,	lbs.	7.3
Equivalent from and at 212°,	lbs.	7.74

PER POUND OF COMBUSTIBLE.

Apparent,	lbs.	8.25
Actual,	lbs.	7.99
Equivalent from and at 212°,	lbs.	9.47

PER SQUARE FOOT HEATING SURFACE PER HOUR.

Actual,	lbs.	1.86
Equivalent from and at 212°,	lbs.	1.97

HORSE POWER.

On basis 34½ lbs. equiv. evap. per hour,	H. P.	143.3
Builders Rating,	H. P.	200
Ratio of Commercial to Builders Rating,		.573

ANALYSIS OF FUEL.

Fixed Carbon,	per cent.	
Volatile Matter,	per cent.	
Moisture,	per cent.	5.1
Ash, Dry Coal Basis	per cent.	8.62
Combustible, " " "	per cent.	91.3
Calorific Value per lb. of Fuel as Fired,	B. T. U.	11904
Calorific Value per lb. of dry Fuel,	B. T. U.	12544
Calorific Value per lb. of Combustible,	B. T. U.	13,750
Heat Generated per hour per lb. dry coal,	B. T. U.	11,650
Heat Generated per hour per lb. of *Combustible as Fired*,	B. T. U.	12,710
Heat Absorbed per hour per lb. dry coal,	B. T. U.	7,740
Heat Absorbed per hour per lb. of *Combustible as Burned*,	B. T. U.	9,120
Efficiency of Boiler and Grate,	per cent.	61.75
Efficiency of Boiler,	per cent.	61.25

COST OF VAPORATING WATER.

Cost of Coal, Dollars per ton,	2.10
Cost of Evap. 1,000 lbs. of Water from and at 212°,	14.3 ¢
Depth of Fire	5 1/4"
Grate Speed in feet per hour	9.32.

RUNNING LOG

TEST NO 2 — April 2, '10 PM

Time	Press	Fuel	Meter	Temperature Feed	Flue	Cal	O	CO_2
2:41	80	0	2145	161	620	233		
3:11	83	4190	2380	170		232		
3:30	89	3635	2638	170	640	243		
4:00	80	3695	2937	166	625	239	9.5	6.5
4:30	75	4990	3210	167		238		
5:00	80	4225	3474	180	630	238		
5:30	75	4850	3807	182	625	235	9.5	6.7
6:00	83	4200	4005	157	607	235		
6:30	73	4320	4200	188	600	226		
7:00	83	6220	4525	179	580	231		
7:30	103	4315	4790	177	600	238		
8:05	90	4360	5175	172	640	237	9.5	6.6
8:30	95	4175	5380	152	620	237		
8:55	77	6290	5690	154	620	228		
9:30	79	4905	5992	158	620	222		
9:48	68	3700	6227	156	620	224		
Total		68070	4082					
Ave.	82.0			1681	6177	2335	9.5	6.6

Depth of Fuel	5¾"
Speed of Grate, Ft. per Hr.	13.67'
Draft, Inches Water	⅛"
Weight of Wet Refuse	1062.5#
Length of Run	7 hrs

A.A. Byers
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MECHANICAL ENGINEERING LABORATORY

ARMOUR INSTITUTE OF TECHNOLOGY

Report of Boiler Test made At Armour Institute of Technology

For Thesis — No 2 *Date* May 2 (P.M)

Duration of Trial,	hours.	7.01
Kind of Boiler,		Stirling
Kind of Grate,		Mc Kenzie
Grate Surface, length 9½ ft., width 5¼ ft.	sq. ft.	50
Water Heating Surface,	sq. ft.	2000
Superheating Surface,	sq. ft.	none
Area, Chimney,	sq. ft.	38.48
Height, Chimney,	ft.	175
Ratio Heating to Grate Surface,		40 : 1

AVERAGE PRESSURES.

Barometer,	ins. mercury.	29.5
Steam Gauge,	lbs. per sq. in.	82.03
Absolute Steam Pressure,	lbs. per sq. in.	96.53
Draught Gauge,	ins. water.	1" / 8

AVERAGE TEMPERATURES.

External Air,	deg. F.	54
Boiler Room,	deg. F.	62
Flue,	deg. F.	617.7
Furnace,	deg. F.	—
Feed Water,	deg. F.	168.1
Steam,	deg. F.	233.5

FUEL.

Total Coal Consumed,	lbs.	6807
Moisture in Coal,	lbs.	347.8
Dry Coal Consumed,	lbs.	6459.2
Total Refuse, Dry,	lbs.	784.69
Total Refuse, Dry, Dry Coal Basis	per cent.	12.1
Total Combustible,	lbs.	5903.7
Combustible, Dry Coal Basis	per cent.	91.4

FUEL PER HOUR.

Coal as Fired per hour,	lbs.	971.04
Dry Coal, per hour,	lbs.	921.5
Combustible, per hour,	lbs.	842.1
Dry Coal, per sq. foot of Grate,	lbs.	16.19

TOTAL WATER.

Quality of Steam,	per cent.	97.2
Total Weight Water Used,	lbs.	46,826
Total Evaporated into Dry Steam,	lbs.	45,515
Factor of Evaporation,		1.054
Total from and at 212°,	lbs.	47973

WATER PER HOUR.

Amount Used, Apparently Evaporated,	lbs.	6680
Evaporated into Dry Steam,	lbs.	6493
Evaporated from and at 212°,	lbs.	6843.6

EVAPORATION.

PER POUND OF FUEL AS FIRED

Apparent,	lbs.	6.88
Actual,	lbs.	6.68
Equivalent from and at 212°,	lbs.	7.04

PER POUND DRY COAL.

Apparent,	lbs.	7.24
Actual,	lbs.	7.04
Equivalent from and at 212°,	lbs.	7.42

PER POUND OF COMBUSTIBLE.

Apparent,	lbs.	7.93
Actual,	lbs.	7.79
Equivalent from and at 212°,	lbs.	8.12

PER SQUARE FOOT HEATING SURFACE PER HOUR.

Actual,	lbs.	2.59
Equivalent from and at 212°,	lbs.	2.74

HORSE POWER.

On basis 34½ lbs. equiv. evap. per hour,	H. P.	198.3
Builders Rating,	H. P.	200
Ratio of Commercial to Builders Rating,		.793

ANALYSIS OF FUEL.

Fixed Carbon,	per cent.	
Volatile Matter,	per cent.	
Moisture,	per cent.	5.1
Ash, Dry Coal Basis	per cent.	8.62
Combustible, " " "	per cent.	91.38
Calorific Value per lb. of Fuel as Fired,	B. T. U.	11904
Calorific Value per lb. of dry Fuel,	B. T. U.	12,544
Calorific Value per lb. of Combustible,	B. T. U.	13,750
Heat Generated per hour per lb. dry coal,	B. T. U.	12,000
Heat Generated per hour per lb. of *Combustible as Fired*,	B. T. U.	13,180
Heat Absorbed per hour per lb. dry coal,	B. T. U.	7425
Heat Absorbed per hour per lb. of *Combustible as Burned*,	B. T. U.	8430
Efficiency of Boiler and Grate,	per cent.	59.25
Efficiency of Boiler,	per cent.	62.3

COST OF VAPORATING WATER.

Cost of Coal, Dollars per ton,	2.10
Cost of Evap. 1,000 lbs. of Water from and at 212°,	14.9¢
Depth of fire	5¼"
Speed of Grate in feet per hour	13.67

RUNNING LOG

TEST NO 3 — April 3 10 AM

Time	Press	Fuel	Meter	Temperature Feed	Temperature Flue	Cal	O	CO_2
7:20	95	0	8531	163		234		
8:00	94	6060	9015	152		233	6.5	4.5
8:30	107	7445	9206	184	600	237		
9:00	80	2865	9503	168	530	226		
9:30	110	5810	0930	169	625	239		
10:00	75	3525	0300	188	550	218	9.0	6.5
10:30	93	6610	0710	153	607	233		
11:00	85	4870	1085	157	585	226	5.2	7.8
11:30	100	5630	1277	149	580	221		
12:00	105	5430	1586	170	550	231		
12:30	107	4060	1903	142	600	233		
1:00	97	3985	2037	169	600	226	9.5	6.6
1:30	79	4700	2360	138	540	218		
2:00	102	4085	2804	152	600	242		
2:22	95	3960	2903	163	585	230		
Total		71045	4410					
Ave	949			162.4	581	229.8	7.5	6.1

Depth of Fuel	6½"
Speed of Grate Ft/Hr.	10.8'
Draft Inches Water	1/8"
Weight of Wet Refuse	1358.5
Lengh of Run	7:02

A.A Byers

D.A. Young

MECHANICAL ENGINEERING LABORATORY

ARMOUR INSTITUTE OF TECHNOLOGY

Report of Boiler Test made At Armour Institute of Technology

For Thesis No. 3 *Date* May 3. 1910 (AM)

Duration of Trial,	hours.	7.03
Kind of Boiler,		Stirling
Kind of Grate,		McKenzie
Grate Surface, length ft., width ft.	sq. ft.	50
Water Heating Surface,	sq. ft.	2000
Superheating Surface,	sq. ft.	None
Area, Chimney,	sq. ft.	38.48
Height, Chimney,	ft.	175
Ratio Heating to Grate Surface,		40:1

AVERAGE PRESSURES.

Barometer,	ins. mercury.	
Steam Gauge,	lbs. per sq. in.	94.93
Absolute Steam Pressure,	lbs. per sq. in.	109.33
Draught Gauge,	ins. water.	1/8"

AVERAGE TEMPERATURES.

External Air,	deg. F.	52
Boiler Room,	deg. F.	61
Flue,	deg. F.	581
Furnace,	deg. F.	
Feed Water,	deg. F.	162.5
Steam, Calorimeter	deg. F.	233.0

FUEL.

Total Coal Consumed,	lbs.	7104.5
Moisture in Coal,	lbs.	363.
Dry Coal Consumed,	lbs.	6741.5
Total Refuse, Dry,	lbs.	1088.
Total Refuse, Dry, dry basis	per cent.	16.2
Total Combustible,	lbs.	6162
Combustible, dry basis	per cent.	91.4

FUEL PER HOUR.

Coal as Fired per hour,	lbs.	1010.6
Dry Coal, per hour,	lbs.	959.
Combustible, per hour,	lbs.	876.5
Dry Coal, per sq. foot of Grate,	lbs.	19.2

TOTAL WATER.

Quality of Steam,	per cent.	96.9
Total Weight Water Used,	lbs.	49914
Total Evaporated into Dry Steam,	lbs.	48438
Factor of Evaporation,		1.0620
Total from and at 212°,	lbs.	53,011

WATER PER HOUR.

Amount Used, Apparently Evaporated,	lbs.	7060
Evaporated into Dry Steam,	lbs.	6851
Evaporated from and at 212°,	lbs.	7498

EVAPORATION.

PER POUND OF FUEL AS FIRED

Apparent,	lbs.	6.98
Actual,	lbs.	6.78
Equivalent from and at 212°,	lbs.	7.42

PER POUND DRY COAL.

Apparent,	lbs.	7.35
Actual,	lbs.	7.14
Equivalent from and at 212°,	lbs.	7.82

PER POUND OF COMBUSTIBLE.

Apparent,	lbs.	8.07
Actual,	lbs.	7.84
Equivalent from and at 212°,	lbs.	8.56

PER SQUARE FOOT HEATING SURFACE PER HOUR.

Actual,	lbs.	2.82
Equivalent from and at 212°,	lbs.	3.00

HORSE POWER.

On basis 34½ lbs. equiv. evap. per hour,	H. P.	217.3
Builders Rating,	H. P.	200.0
Ratio of Commercial to Builders Rating,		87.0%

ANALYSIS OF FUEL.

Fixed Carbon,	per cent.	
Volatile Matter,	per cent.	
Moisture,	per cent.	5.11
Ash, dry coal basis	per cent.	8.62
Combustible,	per cent.	91.38
Calorific Value per lb. of Fuel as Fired,	B. T. U.	11,900
Calorific Value per lb. of dry Fuel,	B. T. U. per cent.	12,544
Calorific Value per lb. of Combustible,	B. T. U.	13,727
Heat Generated per hour per lb. dry coal,	B. T. U.	10580
Heat Generated per hour per lb. of *Combustible as Fired*,	B. T. U.	12546.
Heat Absorbed per hour per lb. dry coal,	B. T. U.	7580
Heat Absorbed per hour per lb. of *Combustible as Burned*,	B. T. U.	9042
Efficiency of Boiler and Grate,	per cent.	60.4
Efficiency of Boiler,	per cent.	65.8

COST OF VAPORATING WATER.

Cost of Coal, Dollars per ton,		$2.10
Cost of Evap. 1,000 lbs. of Water from and at 212°,		14.14 ¢
Depth of Fire		6½
Speed of Grate in ft. per hour		10.78

RUNNING LOG

TEST NO 4 — April 3, '10 P.M.

Time	Press.	Fuel	Meter	Temperature Feed	Flue	Cal	O	CO_2
3.25	110	0	3451	193	625	240	90	7.0
4.00	92	490.0	3973	158	580	228		
4.30	95	434.5	4235	159	590	240		
5:00	93	405.5	4466	163	580	237		
5:30	97	417.5	4596	171	600	239	8.5	6.5
6:00	70	344.5	4907	158	560	221		
6:30	78	416.0	5146	157	570	225		
7:00	96	423.0	5332	171		237		
7.30	85	480.0	5713	168	620	235	9.5	6.7
8:00	87	420.0	5967	167		237		
8:30	96	460.5	6104	178	625	239		
9:00	87	479.5	6383	160	620	225		
9:30	92	403.5	6587	168	620	239	9.5	6.6
9:35	84	150.0	6598	168	610	238		
Total		5338.5	3147	2339				
Av.	90			167.0	600	234.3	9.1	6.7

Depth of Fuel	4½"
Speed of Grate, Ft./Hr	9.32'
Draft – Inches Water	⅛"
Weight of Wet Refuse	1045
Length of Run	6.10

A.A. Byers

D.A. Young

MECHANICAL ENGINEERING LABORATORY

ARMOUR INSTITUTE OF TECHNOLOGY

Report of Boiler Test made At Armour Institute of Technology

For Thesis No 4 *Date* May 3, 1910 (P.M.)

Duration of Trial,	hours.	6.17
Kind of Boiler,		Stirling
Kind of Grate,		McKenzie
Grate Surface, length ft., width ft.	sq. ft.	50
Water Heating Surface,	sq. ft.	2000
Superheating Surface,	sq. ft.	None
Area, Chimney,	sq. ft.	38.48
Height, Chimney,	ft.	175'
Ratio Heating to Grate Surface,		40.1

AVERAGE PRESSURES.

Barometer,	ins. mercury.	29.5
Steam Gauge,	lbs. per sq. in.	90.0
Absolute Steam Pressure,	lbs. per sq. in.	104.4
Draught Gauge,	ins. water.	1/8"

AVERAGE TEMPERATURES.

External Air,	deg. F.	56
Boiler Room,	deg. F.	72
Flue,	deg. F.	600
Furnace,	deg. F.	
Feed Water,	deg. F.	167
Steam, Calorimeter	deg. F.	238

FUEL.

Total Coal Consumed,	lbs.	5339.5
Moisture in Coal,	lbs.	272.3
Dry Coal Consumed,	lbs.	5067.2
Total Refuse, Dry,	lbs.	837.1
Total Refuse, Dry, dry basis	per cent.	16.5
Total Combustible,	lbs.	4631.4
Combustible, dry basis	per cent.	91.4

FUEL PER HOUR.

Coal as Fired per hour,	lbs.	865.3
Dry Coal, per hour,	lbs.	821.2
Combustible, per hour,	lbs.	750.6
Dry Coal, per sq. foot of Grate,	lbs.	16.4

TOTAL WATER.

Quality of Steam,	per cent.	97.5
Total Weight Water Used,	lbs.	37,390
Total Evaporated into Dry Steam,	lbs.	36,452
Factor of Evaporation,		1.0617
Total from and at 212°,	lbs.	39,638

WATER PER HOUR.

Amount Used, Apparently Evaporated,	lbs.	6060
Evaporated into Dry Steam,	lbs.	5908
Evaporated from and at 212°.	lbs.	6934

EVAPORATION.

PER POUND OF FUEL AS FIRED

Apparent,	lbs.	7.00
Actual,	lbs.	6.83
Equivalent from and at 212°,	lbs.	7.44

PER POUND DRY COAL.

Apparent,	lbs.	7.38
Actual,	lbs.	7.20
Equivalent from and at 212°,	lbs.	7.85

PER POUND OF COMBUSTIBLE.

Apparent,	lbs.	8.06
Actual,	lbs.	7.88
Equivalent from and at 212°,	lbs.	8.56

PER SQUARE FOOT HEATING SURFACE PER HOUR.

Actual,	lbs.	2.43
Equivalent from and at 212°,	lbs.	2.57

HORSE POWER.

On basis 34½ lbs. equiv. evap. per hour,	H. P.	186.5
Builders Rating,	H. P.	200
Ratio of Commercial to Builders Rating,		74.7

ANALYSIS OF FUEL.

Fixed Carbon,	per cent.	
Volatile Matter,	per cent.	
Moisture, wet coal basis	per cent.	5.11
Ash, dry coal basis	per cent.	8.62
Combustible, dry coal basis	per cent.	91.38
Calorific Value per lb. of Fuel as Fired,	B. T. U.	11,900
Calorific Value per lb. of dry Fuel,	~~B. T. U. per cent.~~	12,514
Calorific Value per lb. of Combustible,	B. T. U.	13727
Heat Generated per hour per lb. dry coal,	B. T. U.	11553
Heat Generated per hour per lb. of *Combustible as Fired*,	B. T. U.	12642
Heat Absorbed per hour per lb. dry coal,	B. T. U.	7597
Heat Absorbed per hour per lb. of *Combustible as Burned*,	B. T. U.	9099
Efficiency of Boiler and Grate,	per cent.	60.6
Efficiency of Boiler,	per cent.	66.3

COST OF VAPORATING WATER.

Cost of Coal, Dollars per ton,		$2.10
Cost of Evap. 1,000 lbs. of Water from and at 212°,		14.11¢
Depth of fire		4½"
Speed of Grate in ft per hour.		9.32

RUNNING LOG

TEST NO. 5 — May 4, '10 AM

Time	Press	Fuel	Meter	Temperature Feed	Flue	Cal	O	CO_2
7.30	95	0	9356	166	575	239		
8.00	97	5335	9536	156	620	237		
8.30	98	5805	9820	178	620	238	6.0	4.0
9.00	97	4350	0282	168	580	238		
9.30	96	4160	0339	168	585	239		
10.00	93	4250	0593	162	580	236		
10.30	85	4320	0935	183	585	235		
11.00	86	4840	1153	167	580	228	9.0	6.0
11.30	80	3605	1279	142	580	228		
12.00	80	4225	1535	141	580	223		
12.30	87	4260	1797	140	580	229		
1.00	97	4715	1937	148	627	232		
1.43	93	3875	2160	166	605	239	9.5	5.5
Total		53920	2804					
Av.	914			1606	5923	234	8.3	5.2

Depth of Fuel	7½"
Speed of Grate Ft/Hr	6.82
Draft Inches Water	⅛"
Weight of Wet Refuse	1085
Length of Run	813

AA Byers

D.A. Young

MECHANICAL ENGINEERING LABORATORY

ARMOUR INSTITUTE OF TECHNOLOGY

Report of Boiler Test made At Armour Institute of Technology

For Thesis No 5 *Date* May 4, 1910

Duration of Trial,	hours.	6.21
Kind of Boiler,		Stirling
Kind of Grate,		McKenzie
Grate Surface, length 9½ ft., width 5¼ ft.	sq. ft.	50
Water Heating Surface,	sq. ft.	2000
Superheating Surface,	sq. ft.	none
Area, Chimney,	sq. ft.	38.48
Height, Chimney,	ft.	175
Ratio Heating to Grate Surface,		40 : 1
AVERAGE PRESSURES.		
Barometer,	ins. mercury.	29.5
Steam Gauge,	lbs. per sq. in.	92.2
Absolute Steam Pressure,	lbs. per sq. in.	106.7
Draught Gauge,	ins. water.	⅛"
AVERAGE TEMPERATURES.		
External Air,	deg. F.	52
Boiler Room,	deg. F.	65
Flue,	deg. F.	593
Furnace,	deg. F.	161
Feed Water,	deg. F.	238
Steam,	deg. F.	
FUEL.		
Total Coal Consumed,	lbs.	5392
Moisture in Coal,	lbs.	279.3
Dry Coal Consumed,	lbs.	5112.7
Total Refuse, Dry,	lbs.	909.5
Total Refuse, Dry, Dry Coal Basis	per cent.	17.78
Total Combustible, as Fired.	lbs.	4673
Combustible, Dry Coal Basis	per cent.	91.4
FUEL PER HOUR.		
Coal as Fired per hour,	lbs.	867
Dry Coal, per hour,	lbs.	823.3
Combustible, per hour,	lbs.	666.1
Dry Coal, per sq. foot of Grate,	lbs.	16.46
TOTAL WATER.		
Quality of Steam,	per cent.	97.2
Total Weight Water Used,	lbs.	34318.
Total Evaporated into Dry Steam,	lbs.	33354
Factor of Evaporation,		1.0659
Total from and at 212°,	lbs.	36579
WATER PER HOUR.		
Amount Used, Apparently Evaporated,	lbs.	5520
Evaporated into Dry Steam,	lbs.	5365
Evaporated from and at 212°,	lbs.	5883

EVAPORATION.		
PER POUND OF FUEL AS FIRED		
Apparent,	lbs.	6.37
Actual,	lbs.	6.19
Equivalent from and at 212°,	lbs.	6.70
PER POUND DRY COAL.		
Apparent,	lbs.	6.71
Actual,	lbs.	6.52
Equivalent from and at 212°,	lbs.	7.15
PER POUND OF COMBUSTIBLE.		
Apparent,	lbs.	7.34
Actual,	lbs.	7.11
Equivalent from and at 212°,	lbs.	7.82
PER SQUARE FOOT HEATING SURFACE PER HOUR.		
Actual,	lbs.	2.21
Equivalent from and at 212°,	lbs.	2.35
HORSE POWER.		
On basis 34½ lbs. equiv. evap. per hour,	H. P.	170.5
Builders Rating.	H. P.	200
Ratio of Commercial to Builders Rating,		68.2%
ANALYSIS OF FUEL.		
Fixed Carbon,	per cent.	
Volatile Matter,	per cent.	
Moisture, Dry Coal Basis	per cent.	5.4
Ash, " " "	per cent.	8.6
Combustible, " " "	per cent.	91.4
Calorific Value per lb. of Fuel as Fired,	B. T. U.	11,147
Calorific Value per lb. of dry Fuel,	B. T. U.	11,750
Calorific Value per lb. of Combustible,	B. T. U.	13,662
Heat Generated per hour per lb. dry coal,	B. T. U.	10,671
Heat Generated per hour per lb. of *Combustible as Fired*,	B. T. U.	12.407 8
Heat Absorbed per hour per lb. dry coal,	B. T. U.	6,940
Heat Absorbed per hour per lb. of *Combustible as Burned*,	B. T. U.	8475
Efficiency of Boiler and Grate,	per cent.	59.17
Efficiency of Boiler,	per cent.	62.2
COST OF VAPORATING WATER.		
Cost of Coal, Dollars per ton,		$2.10
Cost of Evap. 1,000 lbs. of Water from and at 212°,		15⅔¢
Depth of Fire		7.5"
Speed of Grate ft. per hour		6.82

RUNNING LOG

TEST NO 6 — May 4 '10 PM

Time	Press	Fuel	Meter	Temperature Feed	Flue	Cal	O	CO_2
2.30	87	0	2364	158	600	235		
3.00	90	272.5	2496	153	615	239	10	5.5
3.30	85	331.5	2746	159	600	231		
4.00	86	341.5	2867	155	600	231		
4.30	88	450.5	3080	174	600	233		
5.00	86	559.0	3209	157	600	224		
5.30	108	403.5	3599	163	600	238	7.0	6.0
6.00	108	458.5	3794	176	600	224		
6.30	82	352.5	4127	152	580	225		
7.00	100	402.0	4285	163	605	232		
7.30	102	402.0	4576	168	600	240		
8.00	89	427.5	4904	182	605	238	8.5	6.5
8.30	86	443.5	5080	165	600	233		
Total		4844.5						
Av.	92.0		2722	164	600	232.5	8.5	6.0

Depth of Fuel	7½"
Speed of Grate Ft/Hr	5.04
Draft Inches Water	1/8"
Weight of Wet Refuse	780
Length of Run	6.00

A.A Byers
D.A. Young

Evaporated from and at 212°, lbs. 5839.5

MECHANICAL ENGINEERING LABORATORY

ARMOUR INSTITUTE OF TECHNOLOGY

Report of Boiler Test made At Armour Institute of Technology

For Therrio ——No 6 *Date* Aby. 4, 1910 (P.M)

Duration of Trial,	hours.	0
Kind of Boiler,		Sterling
Kind of Grate,		McKenzie
Grate Surface, length 9½ ft., width 5¼ ft.	sq. ft.	50
Water Heating Surface,	sq. ft.	2000
Superheating Surface,	sq. ft.	None
Area, Chimney,	sq. ft.	38.48
Height, Chimney,	ft.	175
Ratio Heating to Grate Surface,		40:1

AVERAGE PRESSURES.

Barometer,	ins. mercury.	29.5
Steam Gauge,	lbs. per sq. in.	92.0
Absolute Steam Pressure,	lbs. per sq. in.	106.5
Draught Gauge,	ins. water.	⅛"

AVERAGE TEMPERATURES.

External Air,	deg. F.	52
Boiler Room,	deg. F.	63
Flue,	deg. F.	600
Furnace,	deg. F.	
Feed Water,	deg. F.	164.2
Steam, Calorimeter	deg. F.	236.

FUEL.

Total Coal Consumed,	lbs.	4844.5
Moisture in Coal, 5.1%	lbs.	247.1
Dry Coal Consumed,	lbs.	4597.4
Total Refuse, Dry,	lbs.	669
Total Refuse, Dry, (Moisture 14.2)	per cent.	14.6
Total Combustible,	lbs.	4090.8
Combustible, Dry Coal Basis	per cent.	88.98

FUEL PER HOUR.

Coal as Fired per hour,	lbs.	807.4
Dry Coal, per hour,	lbs.	766.2
Combustible, per hour,	lbs.	681.8
Dry Coal, per sq. foot of Grate, 50'	lbs.	15.3

TOTAL WATER.

Quality of Steam,	per cent.	97.5
Total Weight Water Used,	lbs.	33060
Total Evaporated into Dry Steam,	lbs.	32234
Factor of Evaporation,		1.0598
Total from and at 212°,	lbs.	35037

WATER PER HOUR.

Amount Used, Apparently Evaporated,	lbs.	5510
Evaporated into Dry Steam,	lbs.	5372.3
Evaporated from and at 212°,	lbs.	5839.5

EVAPORATION.

PER POUND OF FUEL AS FIRED

Apparent,	lbs.	6.82
Actual,	lbs.	6.65
Equivalent from and at 212°,	lbs.	7.32

PER POUND DRY COAL.

Apparent,	lbs.	7.19
Actual,	lbs.	7.01
Equivalent from and at 212°,	lbs.	7.62

PER POUND OF COMBUSTIBLE.

Apparent,	lbs.	8.23
Actual,	lbs.	8.03
Equivalent from and at 212°,	lbs.	8.71

PER SQUARE FOOT HEATING SURFACE PER HOUR.

Actual,	lbs.	2.16
Equivalent from and at 212°,	lbs.	2.34

HORSE POWER.

On basis 34½ lbs. equiv. evap. per hour,	H. P.	169
Builders Rating,	H. P.	200
Ratio of Commercial to Builders Rating,		67.6%

ANALYSIS OF FUEL.

Fixed Carbon,	per cent.	
Volatile Matter,	per cent.	
Moisture,	per cent.	5.1
Ash, Dry Basis	per cent.	8.62
Combustible, Dry Basis	per cent.	91.38
Calorific Value per lb. of Fuel as Fired,	B. T. U.	11,900
Calorific Value per lb. of dry Fuel,	B T U per cent.	12,944
Calorific Value per lb. of Combustible,	B. T. U.	13,727
Heat Generated per hour per lb. dry coal,	B. T. U.	11,791
Heat Generated per hour per lb. of *Combustible as Fired*,	B. T. U.	12217
Heat Absorbed per hour per lb. dry coal,	B. T. U.	73895
Heat Absorbed per hour per lb. of *Combustible as Burned*,	B. T. U.	86493
Efficiency of Boiler and Grate,	per cent.	58.9
Efficiency of Boiler,	per cent.	62.8

COST OF VAPORATING WATER.

Cost of Coal, Dollars per ton,	2.10
Cost of Evap. 1,000 lbs. of Water from and at 212°,	14.344
Depth of Fire	7½"
Speed of Grate in ft per hour	5.04

RUNNING LOG

TEST NO 7 — May 12 '10

Time	Press.	Fuel	Meter	Temperature Feed	Flue	Cal	O	CO_2
8:45	100	0	3125	141	600	230		
9:15	100		3247	157	550	242		
9:45	80	832.2	3611	179	600	238	8.2	7.0
10:15	95		3832	148	560	238		
10:45	105	908.0	3989	159	615	240		
11:15	95		4274	164	590	240	9.0	6.0
11:45	102	911.7	4409	152	560	238		
12:15	106		4762	151	560	238	7.5	8.5
12:45	100	810.7	5060	149	550	232		
1:15	110		5223	144	585	238	9.0	7.0
1:45	90	924.5	5662	150	580	234		
2:15	105		5872	190	600	234	10.6	7.5
2:45	103	998.2	5890	193	610	232	9.5	6.5
3:15	100		6432	185	575	233	9.5	6.5
3:45	104	944.3	6834	184	615	233	9.7	6.2
Total		6350.8	3709					
Av	97.2			162.7	590	236.0	9.1	6.9

Depth of Fuel	5¾"
Speed of Grate Ft/Hr	10.95'
Draft, Inches Water	1/8"
Weight of Wet Refuse	10625#
Length of Run	7.00

AA Brers

DA Young

MECHANICAL ENGINEERING LABORATORY

ARMOUR INSTITUTE OF TECHNOLOGY

Report of Boiler Test made At Armour Institute of Technology

For Theis #7 *Date* May 14, 1910

Duration of Trial,	hours.	7
Kind of Boiler,		Sterling
Kind of Grate,		Hand Stoker
Grate Surface, length ft., width ft.	sq. ft.	50
Water Heating Surface,	sq. ft.	2000
Superheating Surface,	sq. ft.	None
Area, Chimney,	sq. ft.	38.48
Height, Chimney,	ft.	175
Ratio Heating to Grate Surface,		40:1

AVERAGE PRESSURES.

Barometer,	ins. mercury.	29.6
Steam Gauge,	lbs. per sq. in.	97.2
Absolute Steam Pressure,	lbs. per sq. in.	111.6
Draught Gauge,	ins. water.	1/8"

AVERAGE TEMPERATURES.

External Air,	deg. F.	55
Boiler Room,	deg. F.	62
Flue,	deg. F.	
Furnace,	deg. F.	590
Feed Water,	deg. F.	162.7
Steam, Calorimeter	deg. F.	239

FUEL.

Total Coal Consumed,	lbs.	6359.6
Moisture in Coal, 6.87%	lbs.	436.9
Dry Coal Consumed,	lbs.	5922.7
Total Refuse, Dry, (Moisture 22.1%)	lbs.	827.7
Total Refuse, Dry, (Dry Basis)	per cent.	13.97
Total Combustible,	lbs.	5431.1
Combustible, Dry Basis	per cent.	91.7

FUEL PER HOUR.

Coal as Fired per hour,	lbs.	908.5
Dry Coal, per hour,	lbs.	846.1
Combustible, per hour,	lbs.	776.
Dry Coal, per sq. foot of Grate,	lbs.	16.9

TOTAL WATER.

Quality of Steam,	per cent.	97.3
Total Weight Water Used,	lbs.	43400
Total Evaporated into Dry Steam,	lbs.	42229
Factor of Evaporation,		1.0656
Total from and at 212°,	lbs.	46247

WATER PER HOUR.

Amount Used, Apparently Evaporated,	lbs.	6200
Evaporated into Dry Steam,	lbs.	6033
Evaporated from and at 212°,	lbs.	6607

EVAPORATION.

PER POUND OF FUEL AS FIRED

Apparent,	lbs.	6.82
Actual,	lbs.	6.64
Equivalent from and at 212°,	lbs.	7.27

PER POUND DRY COAL.

Apparent,	lbs.	7.33
Actual,	lbs.	7.13
Equivalent from and at 212°,	lbs.	7.81

PER POUND OF COMBUSTIBLE.

Apparent,	lbs.	7.98
Actual,	lbs.	7.77
Equivalent from and at 212°,	lbs.	8.38

PER SQUARE FOOT HEATING SURFACE PER HOUR.

Actual,	lbs.	2.41
Equivalent from and at 212°,	lbs.	2.64

HORSE POWER.

On basis 34½ lbs. equiv. evap. per hour,	H. P.	191.5
Builders Rating,	H. P.	200
Ratio of Commercial to Builders Rating,		76.6

ANALYSIS OF FUEL.

Fixed Carbon,	per cent.	
Volatile Matter,	per cent.	
Moisture,	per cent.	6.87
Ash, Dry Basis	per cent.	8.19
Combustible, Dry Basis	per cent.	91.8
Calorific Value per lb. of Fuel as Fired,	B. T. U.	11680
Calorific Value per lb. of dry Fuel,	~~B. T. U. per coal.~~	12544
Calorific Value per lb. of Combustible,	B. T. U.	13727
Heat Generated per hour per lb. dry coal,	B. T. U.	10788
Heat Generated per hour per lb. of *Combustible as Fired*,	B. T. U.	12932
Heat Absorbed per hour per lb. dry coal,	B. T. U.	75721
Heat Absorbed per hour per lb. of *Combustible as Burned*,	B. T. U.	88018
	B. T. U.	88018
Efficiency of Boiler and Grate,	per cent.	60.3
Efficiency of Boiler,	per cent.	64.3

COST OF VAPORATING WATER.

Cost of Coal, Dollars per ton,		$2.10
Cost of Evap. 1,000 lbs. of Water from and at 212°,		$.1445
Depth of Fire		5¾"
Speed of Grate in ft/hr.		10.95

RUNNING LOG

TEST No8 — May 12 '10 —

Time	Press	Fuel	Meter	Temperature Feed	Flue	Cal.	O	CO_2
7.45	92	0	1178	185	538	230		
8:15	102		1429	138	520	238	7.0	5.5
8:45	93	1384	1712	172	500	230		
9:15	97		1977	169	500	234	9.5	5.0
9:45	100		2127	165	565	236		
10:15	92	935	2581	164	555	230	8.0	5.5
10:45	98		2772	141	550	238	6.0	5.2
11:15	98	825	2920	150	500	236		
11:45	89		3278	163	550	228	7.0	5.0
12:15	89	550	3387	161	540	227	6.5	5.2
12:45	112		3567	162	530	230		
1:15	110	1100	3754	161.5	500	228		
1:45	103		4019	159	520	235		
2:15	107	825	4328	171	610	232		
2:45	109	550	4654	168	600	240		
Total		6179	3476					
Av.	98.7			155.7	540	233	7.3	5.3

Depth of Fuel	7"
Speed of Grate Ft/Hr.	7.58
Draft - Inches Water	1/16"
Weight of Wet Refuse	1197
Length of Run	7:00

A.A. Byers

D.A. Young

MECHANICAL ENGINEERING LABORATORY

ARMOUR INSTITUTE OF TECHNOLOGY

Report of Boiler Test made At Armour Institute of Technology

For Theis No 8 *Date* May 12, 1910

Duration of Trial,	hours.	7
Kind of Boiler,		Stirling
Kind of Grate,		Underfeed
Grate Surface, length ft., width ft.	sq. ft.	50
Water Heating Surface,	sq. ft.	2000
Superheating Surface,	sq. ft.	None
Area, Chimney,	sq. ft.	38.48
Height, Chimney,	ft.	175
Ratio Heating to Grate Surface,		40:1

AVERAGE PRESSURES.

Barometer,	ins. mercury.	29.52
Steam Gauge,	lbs. per sq. in.	98.7
Absolute Steam Pressure,	lbs. per sq. in.	113.2
Draught Gauge,	ins. water.	1/16

AVERAGE TEMPERATURES.

External Air,	deg. F.	52
Boiler Room,	deg. F.	61
Flue,	deg. F.	540
Furnace,	deg. F.	
Feed Water,	deg. F.	155.7
Steam, Calorimeter	deg. F.	237

FUEL.

Total Coal Consumed,	lbs.	6179
Moisture in Coal,	lbs.	420
Dry Coal Consumed,	lbs.	5759
Total Refuse, Dry,	lbs.	930
Total Refuse, Dry,	per cent.	16.2
Total Combustible, Dry Basis	lbs.	5263
Combustible, Dry Basis	per cent.	91.3

FUEL PER HOUR.

Coal as Fired per hour,	lbs.	882.9
Dry Coal, per hour,	lbs.	823.0
Combustible, per hour,	lbs.	752.0
Dry Coal, per sq. foot of Grate,	lbs.	16.5

TOTAL WATER.

Quality of Steam,	per cent.	97.2
Total Weight Water Used,	lbs.	41800
Total Evaporated into Dry Steam,	lbs.	40600
Factor of Evaporation,		1.0719
Total from and at 212°,	lbs.	44800

WATER PER HOUR.

Amount Used, Apparently Evaporated,	lbs.	5980
Evaporated into Dry Steam,	lbs.	5813
Evaporated from and at 212°,	lbs.	6410

EVAPORATION.

PER POUND OF FUEL AS FIRED

Apparent,	lbs.	6.78
Actual,	lbs.	6.58
Equivalent from and at 212°,	lbs.	7.26

PER POUND DRY COAL.

Apparent,	lbs.	7.22
Actual,	lbs.	7.02
Equivalent from and at 212°,	lbs.	7.73

PER POUND OF COMBUSTIBLE.

Apparent,	lbs.	7.98
Actual,	lbs.	7.73
Equivalent from and at 212°,	lbs.	8.54

PER SQUARE FOOT HEATING SURFACE PER HOUR.

Actual,	lbs.	2.31
Equivalent from and at 212°,	lbs.	2.57

HORSE POWER.

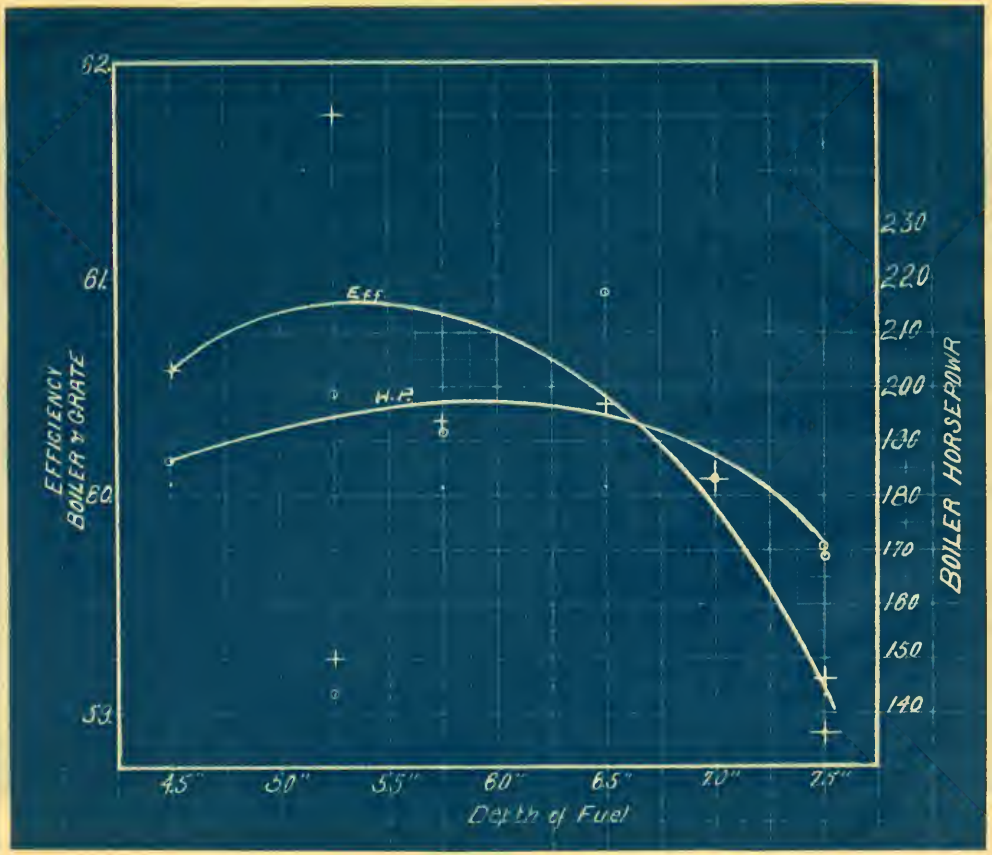
On basis 34½ lbs. equiv. evap. per hour,	H. P.	186
Builders Rating,	H. P.	200
Ratio of Commercial to Builders Rating,		74.4%

ANALYSIS OF FUEL.

Fixed Carbon,	per cent.	
Volatile Matter,	per cent.	
Moisture,	per cent.	6.8
Ash,	per cent.	8.6
Combustible, Dry Basis Dry Basis	per cent.	91.4
Calorific Value per lb. of Fuel as Fired,	B. T. U.	11691
Calorific Value per lb. of dry Fuel,	~~per cent.~~ B. T. U.	12544
Calorific Value per lb. of Combustible,	B. T. U.	13727
Heat Generated per hour per lb. dry coal,	B. T. U.	11591
Heat Generated per hour per lb. of *Combustible as Fired*,	B. T. U.	12683
Heat Absorbed per hour per lb. dry coal,	B. T. U.	12683
Heat Absorbed per hour per lb. of *Combustible as Burned*,	B. T. U.	7552
Efficiency of Boiler and Grate,	per cent.	9008
Efficiency of Boiler,	per cent.	9008
		60.1
		65.4

COST OF VAPORATING WATER.

Cost of Coal, Dollars per ton,		$2.10
Cost of Evap. 1,000 lbs. of Water from and at 212°,		14.5¢
Depth of Fire		7"
Speed of Grate in ft./hr.		7.58


62
61
60
59
EFFICIENCY
BOILER & GRATE
Eff
H.P
230
220
210
200
190
180
170
160
150
140
BOILER HORSEPOWR
4.5"
5.0"
5.5"
6.0"
6.5"
7.0"
7.5"
Depth of Fuel

Average Results

No of Run	1	2	3	4	5	6	7	8
Time of Run (hrs)	4:44	7:07	7:02	6:10	6:13	6:00	7:00	7:00
Feed Water Temp.	162.7	168.1	162.4	167.0	160.6	164.2	162.7	155.7
Meter Read (Gal)	1736	4082	4410	3147	2804	2722	3709	3476
Coal Burned	3186	6807	7104.5	5339.5	5392	4844.5	6358	6179
Calorimiter Temp.	232.5	233.5	229.8	234.3	234.	232.5	236	233
Steam Pressure	93.1	82	94.9	90.	91.4	92	97.2	98.7
Flue Temperature	622.	617.7	581	600	592.8	600	590	540
per cent. Oxygen.	9.4	9.5	7.5	9.4	8.3	8.5	9.1	7.3
" " CO_2	4.8	6.6	6.1	6.7	5.2	6.0	6.9	5.3
Draft (in. water)	1/8"	1/8"	1/8"	1/8"	1/8"	1/8"	1/8"	1/16"
Speed of Grate $^{ft}/_{hr}$	9.32	13.67	10.8	9.32	6.82	5.04	10.95	7.58
Dry Refuse	452	784.7	1088	837.1	909.5	669	82.7	930
Kind of Fuel	Ill. Nut.	Ill. Nut.	Ill. Nut.	Ill. Screen.	Ill. Nut.	Ill. Nut.	Ill. Nut.	Ill. Nut.
Depth of Fire	5 1/4"	5 1/4"	6 1/2"	4 1/2"	7 1/2"	7 1/2"	5 3/4"	7"
Horse Power	143.3	198.3	217.3	186.5	170.5	169	191.5	186
Water Evap at 212°	7.34	7.04	7.42	7.44	6.70	7.32	7.27	7.26
Quality of Steam	96.8	97.2	96.9	97.5	97.2	97.5	97.3	97.2
Eff Boiler & Grate	81.75	58.25	80.10	80.60	59.17	58.90	80.30	80.10
Date of Run	5/2 AM.	5/2 PM	5/3 AM.	5/3 P.M.	5/4 AM.	5/4 PM	5/11 10	5/12/10

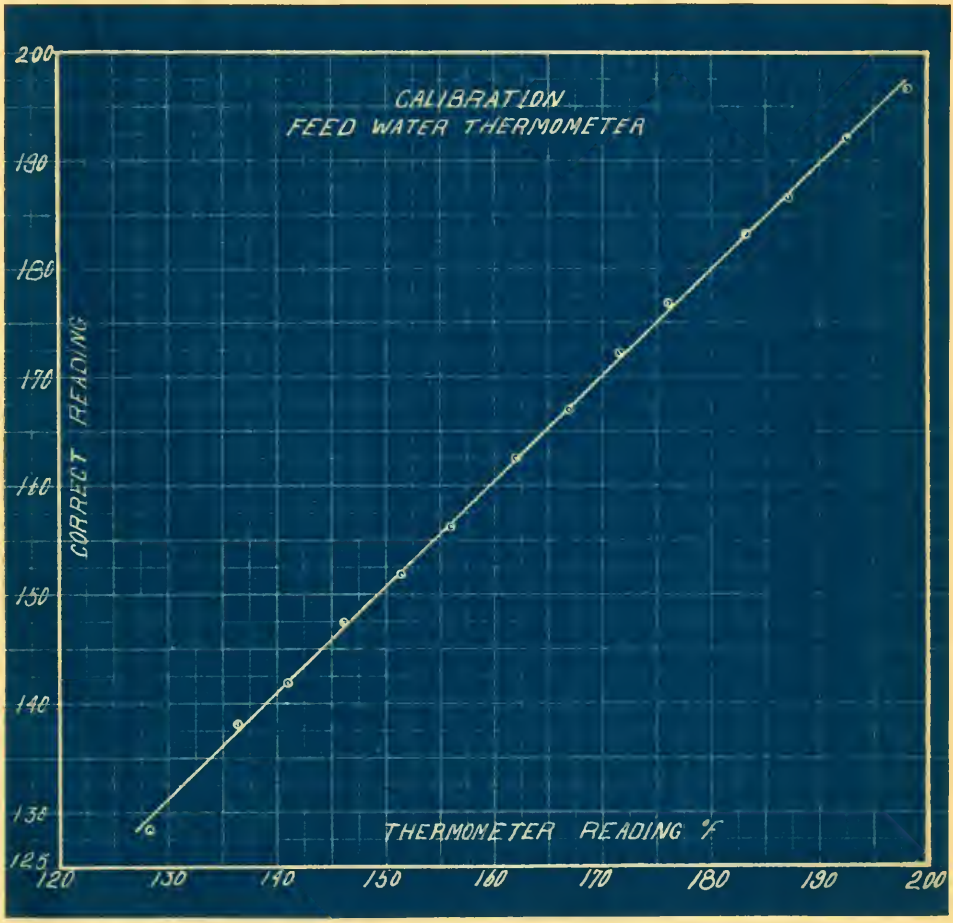
FUEL ANAYSIS

ILLINOIS NUT COAL

Run No	Date	B.T.U.(dry)	Ash(wet)	Moisture-Ash	Moisture-Fuel
1	5/2/10	12850	11.02	14.8	5.11
2	5/2/10	12661	11.02	14.8	5.11
3	5/3/10	12 106	7.33	19.9	5.11
4	5/3/10	12425	——	19.9	5.11
6	5/4/10	12480	——	14.2	5.11
7	5/11/10	12530	8.35	2.21	6.87
7	5/11/10	12850	8.03	22.1	6.87
8	5/12/10	12850	8.35	20.6	6.80
Average	——	12,544	8.62	——	——

ILLINOIS SCREENINGS

Run No	Date	B.T.U.(dry)	Ash (wet)	Moisture-Ash	Moisture-Fuel
5	5/4/10	11540	8.6	14.2	5.18
5	5/4/10	11960	8.6	14.2	5.18
Average	——	11750	——	——	——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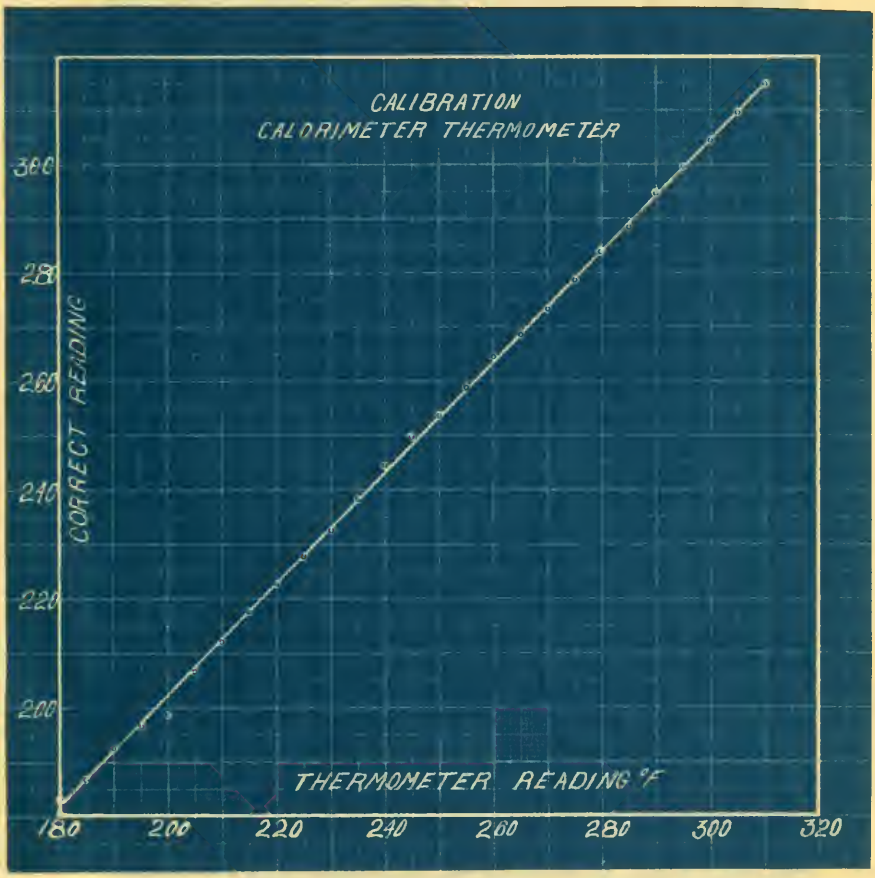
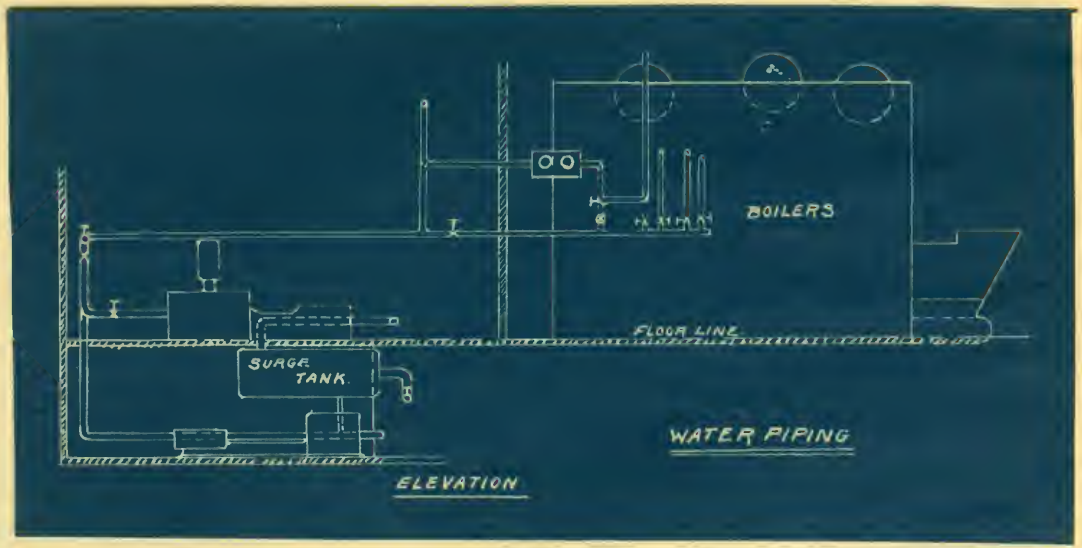
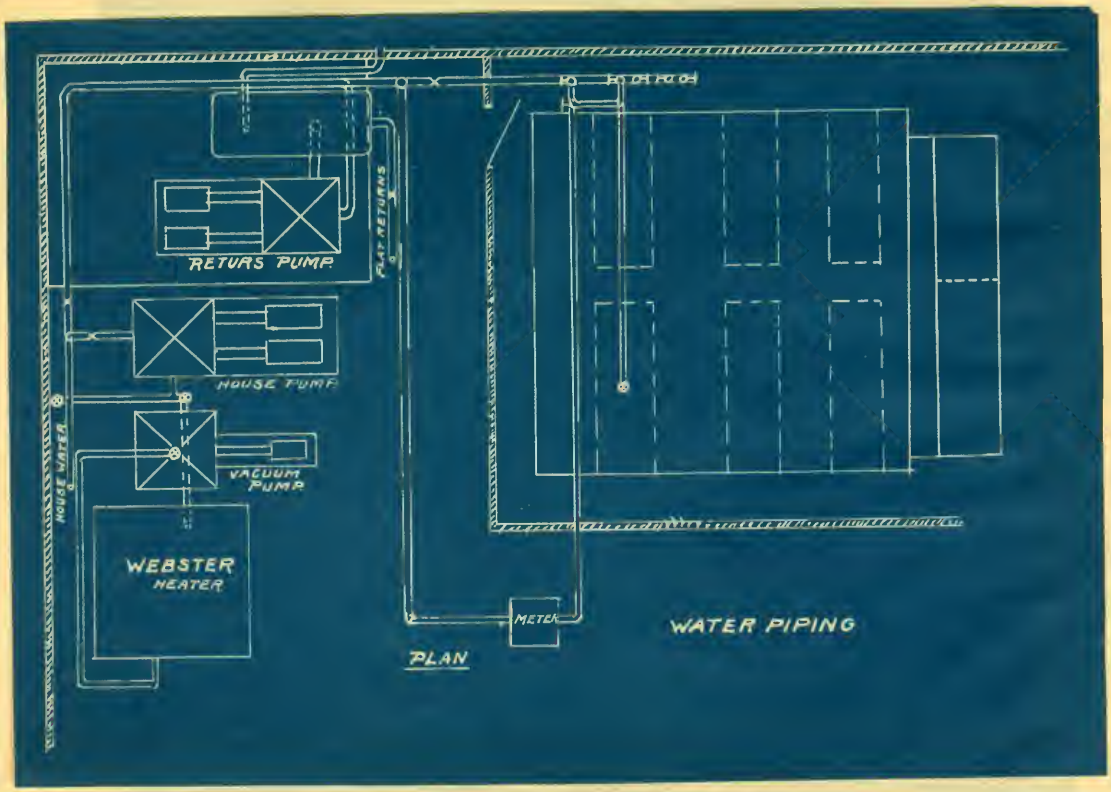
FEED WATER THERMOMETER
CORRECT READING
THERMOMETER READING °F
200
190
180
170
160
150
140
130
125
120
130
140
150
160
170
180
190
200

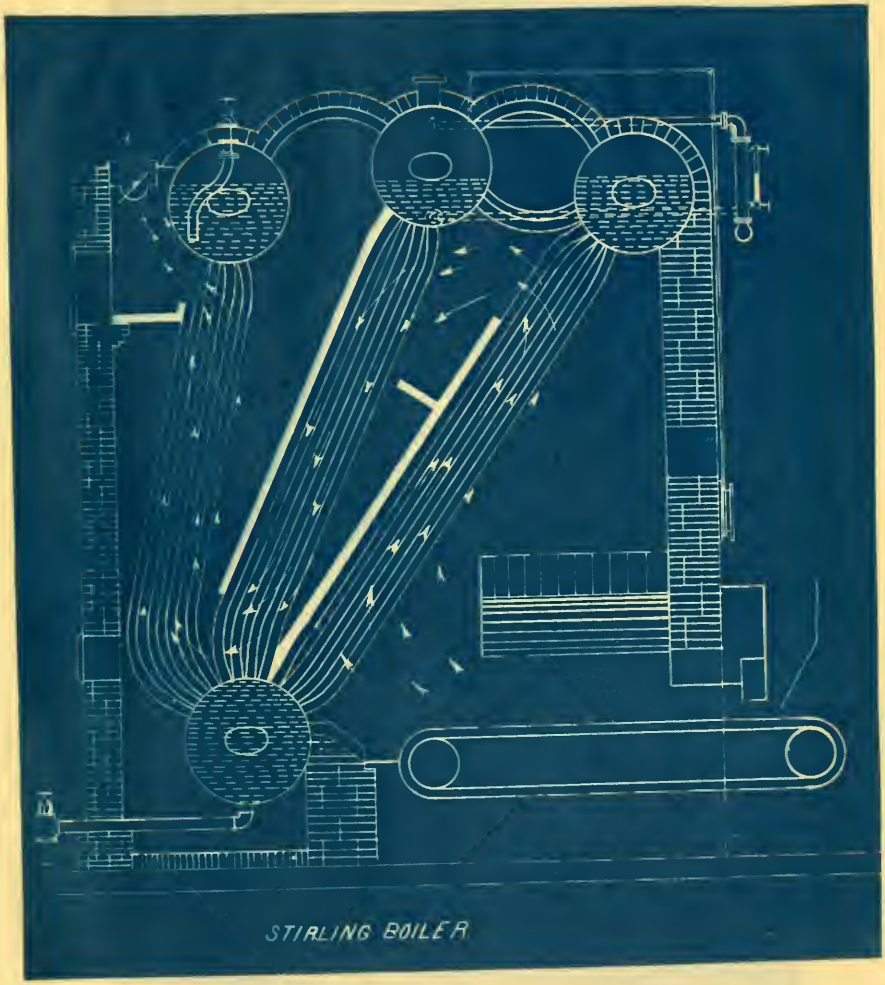

CALIBRATION
CALORIMETER THERMOMETER
CORRECT READING
300
280
260
240
220
200
THERMOMETER READING °F
180
200
220
240
260
280
300
320

Thermometer Corrections

Standard Centigrade	Standard Fahrenheit	Feed Thermometer	Calorimeter Thermometer
53.5	128.3	128.0	130
59.0	138.2	136.0	135
61.0	141.8	141.0	140
64.0	147.2	146.0	145
66.5	151.7	150.5	150
69.0	156.2	156.0	155
72.5	162.5	162.0	160
75.0	167.0	167.0	165
78.0	172.4	171.5	170
80.5	176.9	176.0	175
84.0	183.2	183.0	180
86.0	186.8	187.0	185
89.0	192.2	192.5	190
91.5	196.7	198.0	195
92.5	198.5		200
97.0	206.6		205
100.0	212.0		210
103.0	217.4		215
106.0	222.8		220
108.0	228.2		225
111.5	232.7		230
114.5	238.1		235
118.0	244.4		240
120.5	248.9		245
123.0	253.4		250
126.0	258.8		255
128.0	264.2		260
131.5	268.7		265
134.0	273.2		270
137.0	278.6		275
140.0	284.0		280
142.5	288.5		285
146.0	294.8		290
148.5	299.3		295
151.5	304.7		300
154.0	309.2		305
157.0	314.6		310
162.0	323.6		318


BOILERS
FLOOR LINE
SURGE TANK
WATER PIPING
ELEVATION


RETURN PUMP
FLAT RETURNS
HOUSE PUMP
VACUUM PUMP
WEBSTER HEATER
METER
PLAN
WATER PIPING


STIRLING BOILER

Data For Meter Calibration Curve

Time Minutes	Meter Reading Gals.	Temperature F°	Water Pounds	Gallons Per Hour	Actual Lbs per Hr	Actual Gals per Hr	Slip per Cent
16:41	101	186	1376	365.6	4953.6	611.0	40.5
11:37	101	178	1251	343.4	4252.4	525.0	34.6
10:29	119	157	1293	681.0	7400.0	912.0	26.3
7:45	37	180	521.5	287.0	4040.0	498.0	42.8
9:43	124	166	1281.0	1208.	12,470	1536.0	21.4
16:30	97	149	1195	351.	4315.0	532.0	34.1
12:48	103	150	1203	491.	5640.0	695.0	29.4
9:49	120	187	1249.	732	7620.0	9380	22.0
8:36	99	148	1188.5	690.	8300.0	1024	32.8
10:02	115	143	1162.	690	6980.0	860.0	14.7
9:51	120	132	1302.	732	7440.0	978.0	25.1
5:30	138	131	1312.	1478.	14040.0	1735.0	14.7
5:19	131	132	1265.	1482	14300.0	1787.0	17.07

Average Temperature = 170°F

One Gallon = 8.11#


METER GALLONS/HOUR